

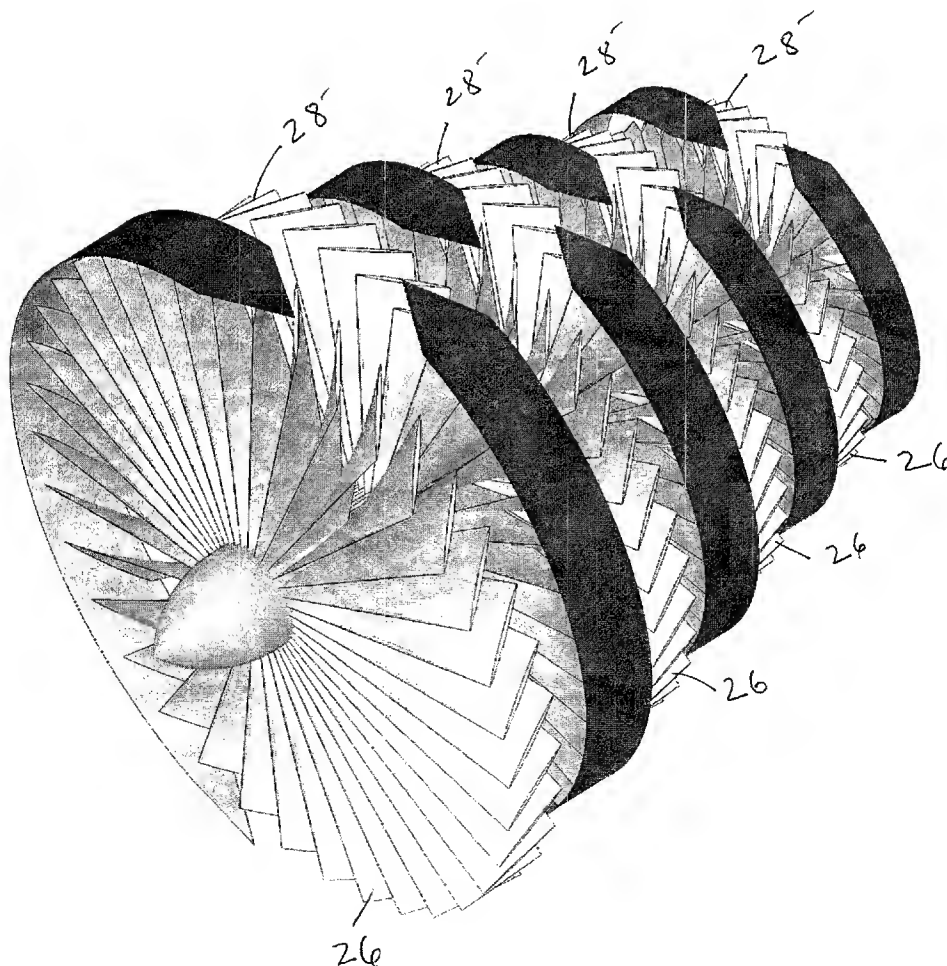


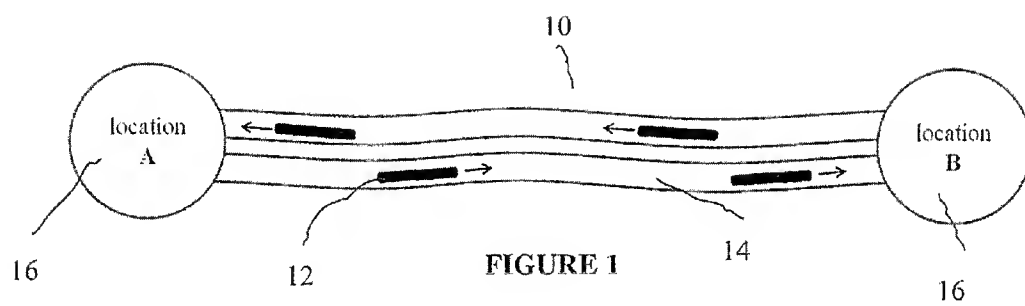
US 20160230768A1

(19) **United States**(12) **Patent Application Publication**  
**BAMBROGAN et al.**(10) **Pub. No.: US 2016/0230768 A1**(43) **Pub. Date: Aug. 11, 2016**(54) **AXIAL COMPRESSOR CONFIGURATION****Publication Classification**(71) Applicant: **HYPERLOOP TECHNOLOGIES, INC.**, Los Angeles, CA (US)(51) **Int. Cl.**  
**F04D 25/06** (2006.01)  
**F04D 29/32** (2006.01)  
**F04D 19/02** (2006.01)(72) Inventors: **Brogan BAMBROGAN**, Los Angeles, CA (US); **Joshua GIEGEL**, Hawthorne, CA (US)(52) **U.S. Cl.**  
CPC ..... **F04D 25/0666** (2013.01); **F04D 19/024** (2013.01); **F04D 29/321** (2013.01)(73) Assignee: **HYPERLOOP TECHNOLOGIES, INC.**, Los Angeles, CA (US)(21) Appl. No.: **15/007,801**(57) **ABSTRACT**(22) Filed: **Jan. 27, 2016****Related U.S. Application Data**

(60) Provisional application No. 62/240,718, filed on Oct. 13, 2015, provisional application No. 62/113,511, filed on Feb. 8, 2015.

An axial compressor includes a housing and a plurality of stages arranged within the housing and along an airflow direction, each stage of the plurality of stages including a first blade assembly and a second blade assembly, wherein the first blade assembly is a rotor, each rotor being drivable independently from the rotors in the other first blade assemblies.





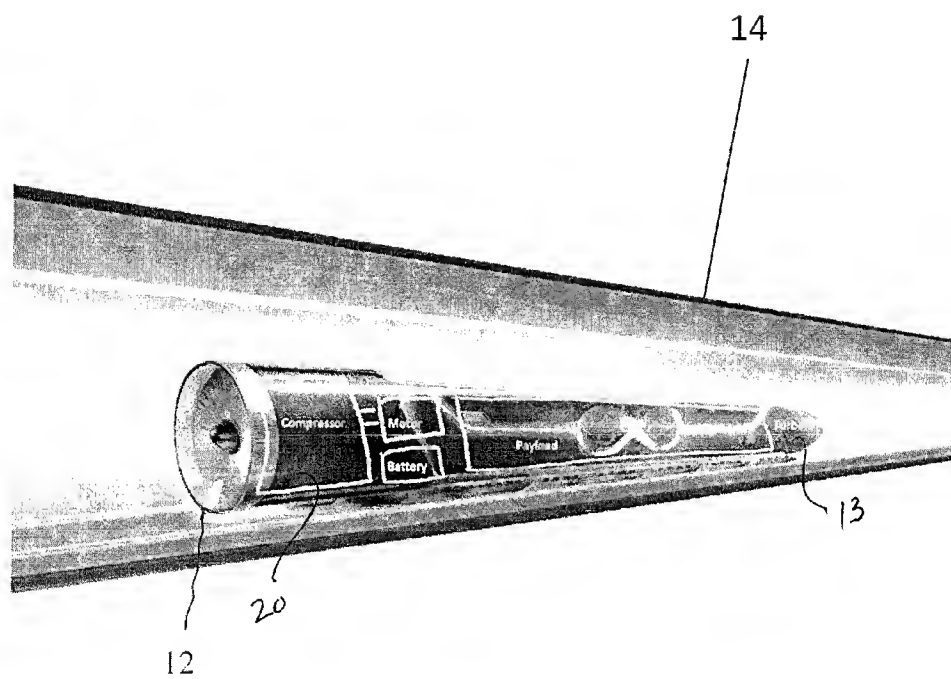
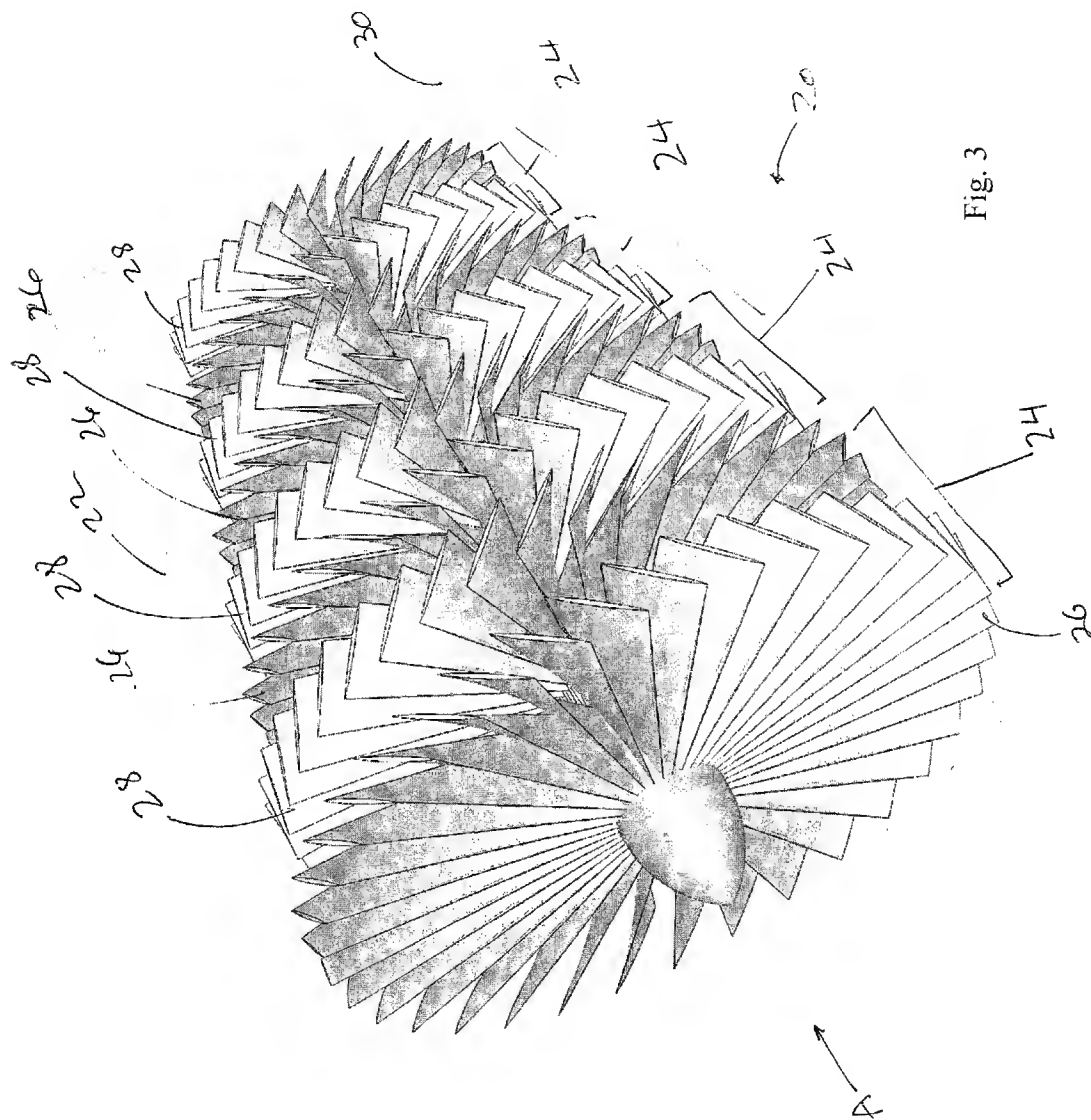


Figure 2



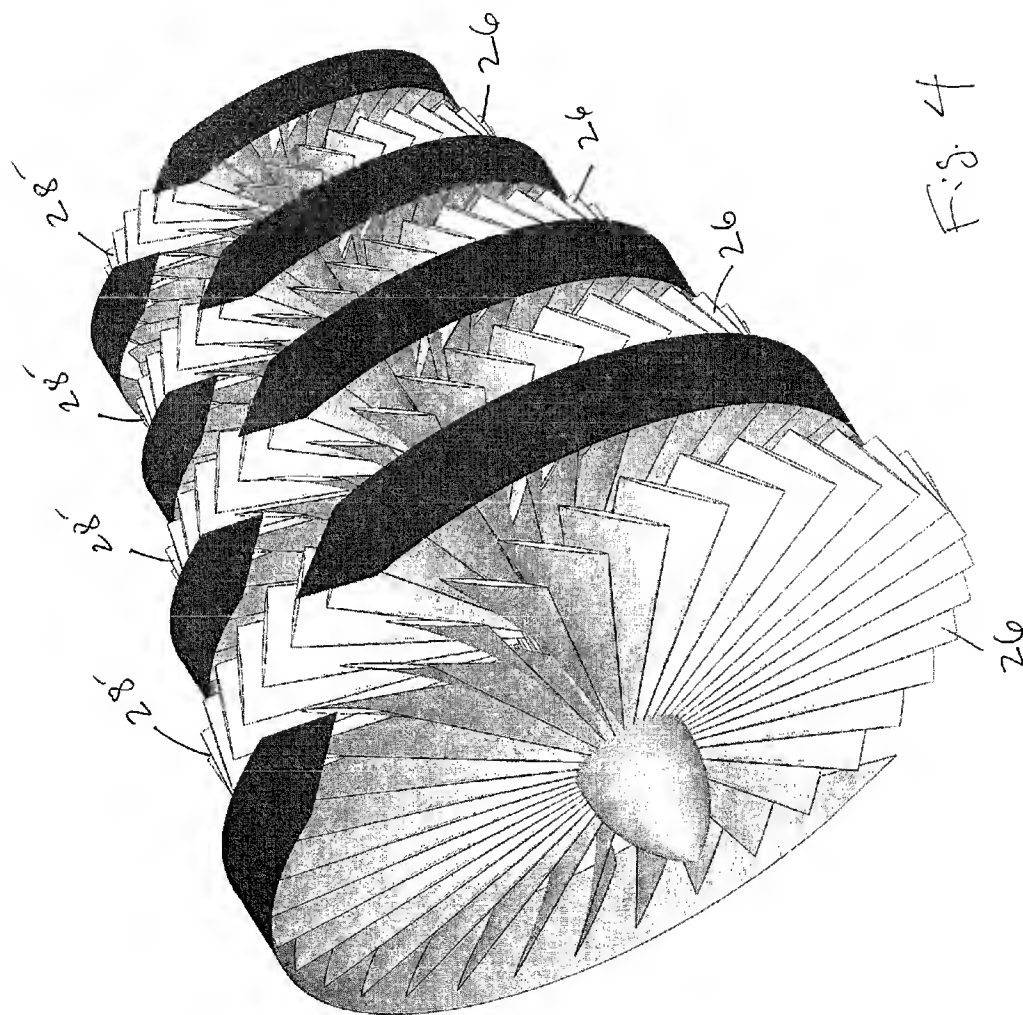


Fig. 4

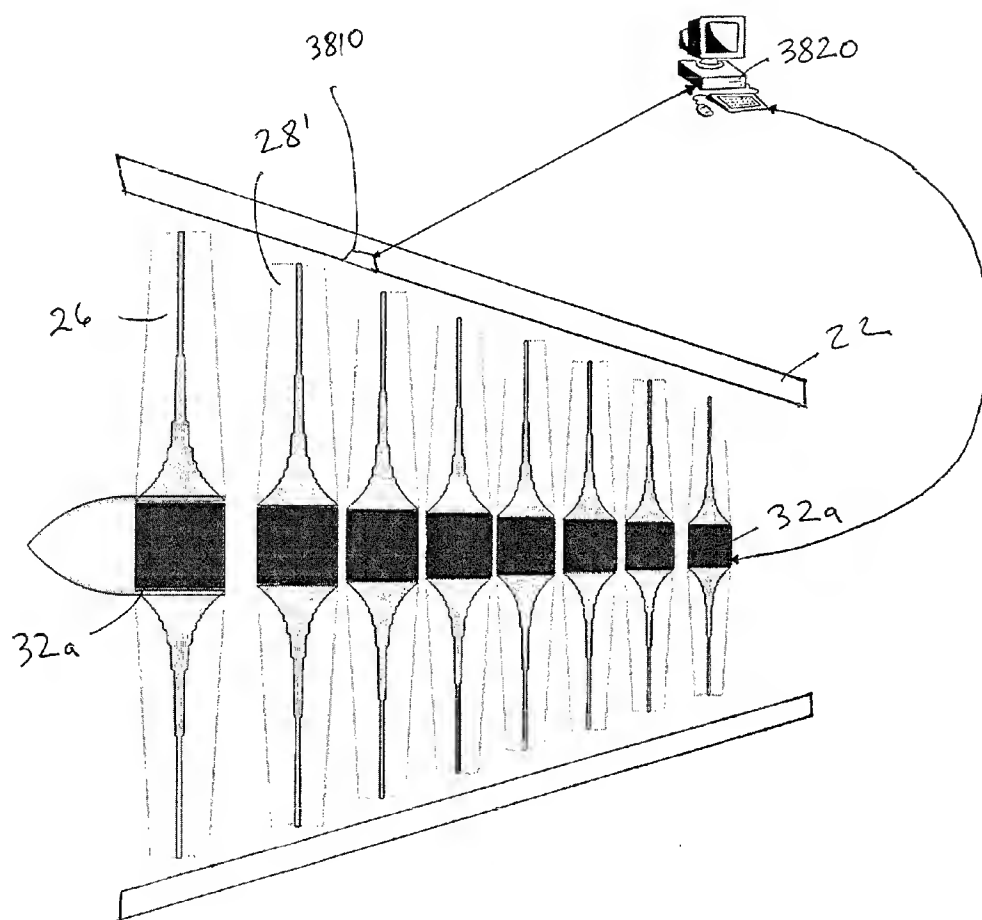


Fig. 5

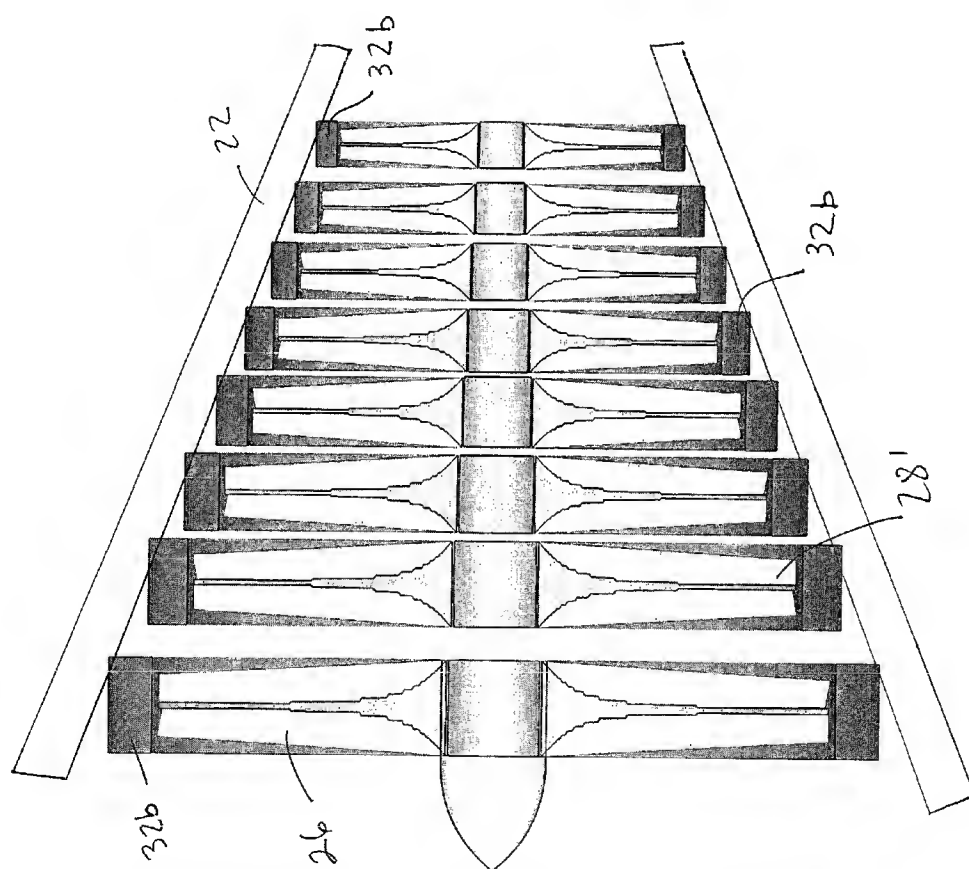


Fig. 6

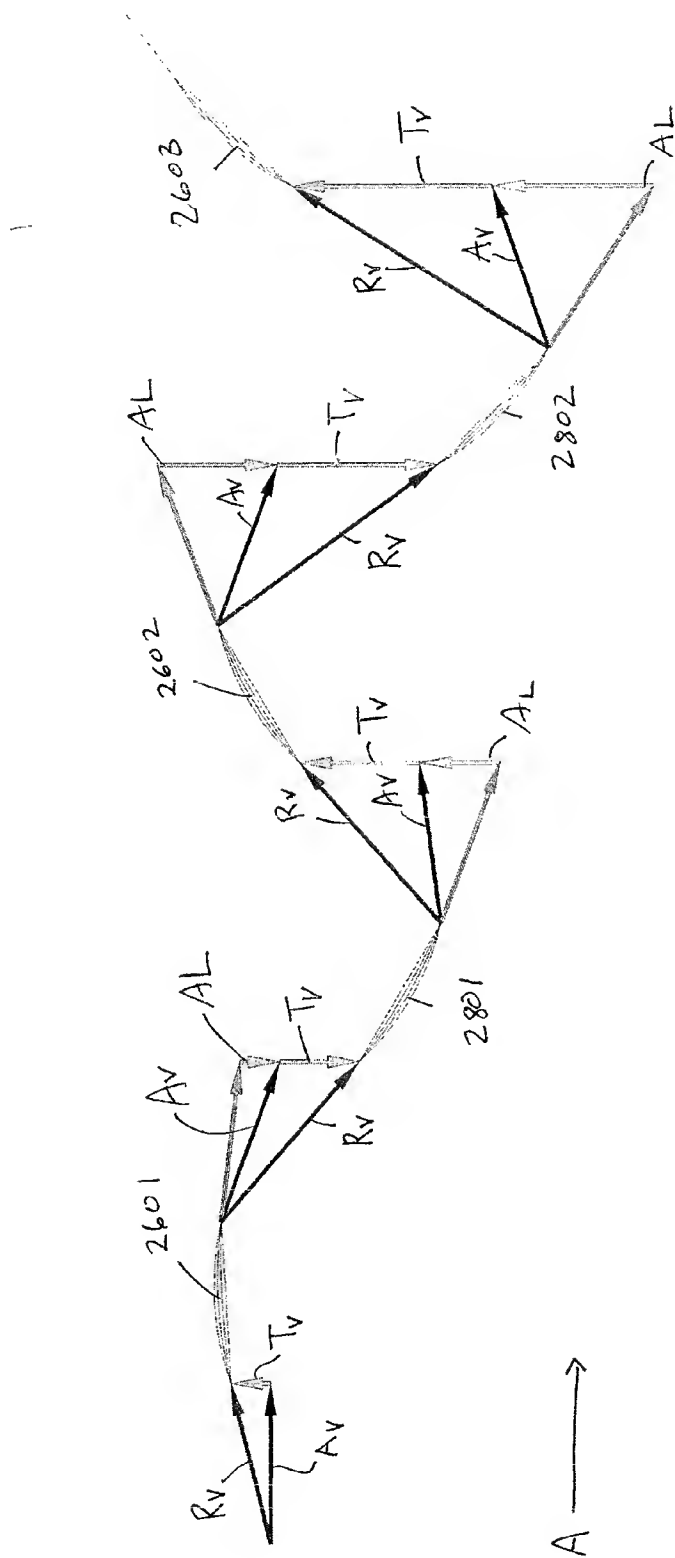


Fig. 7



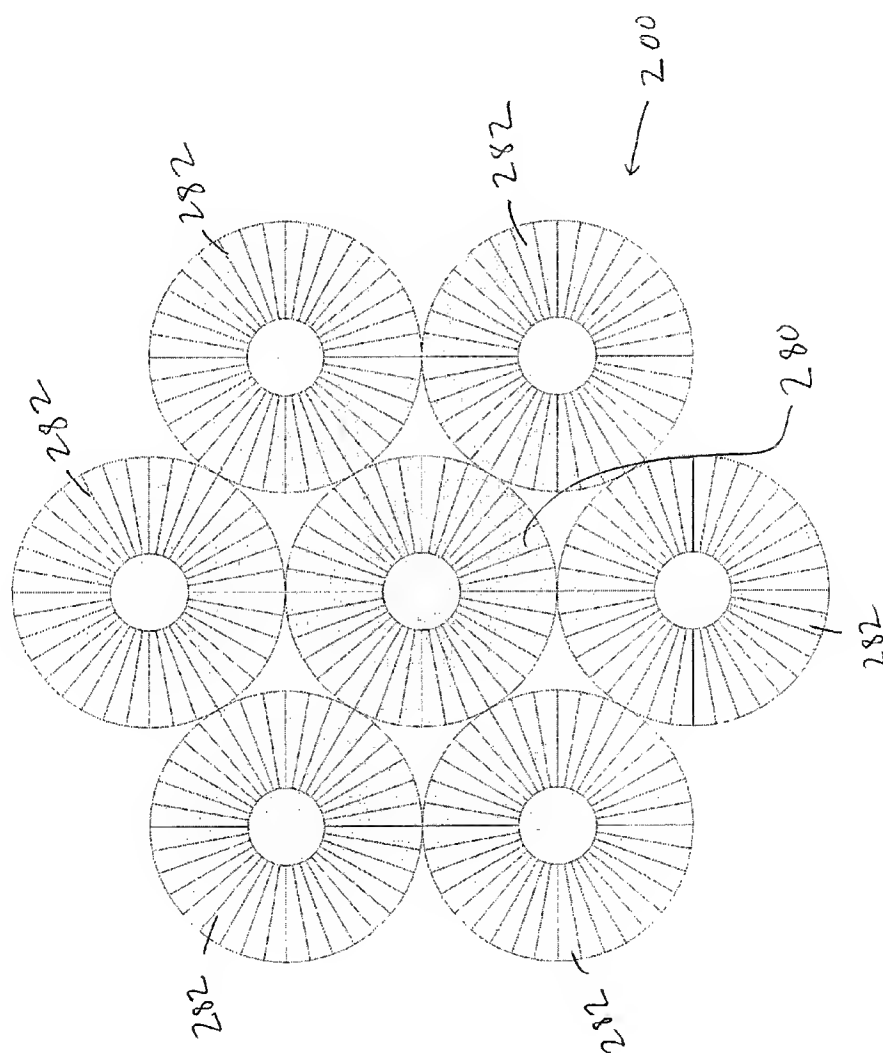


Fig 8

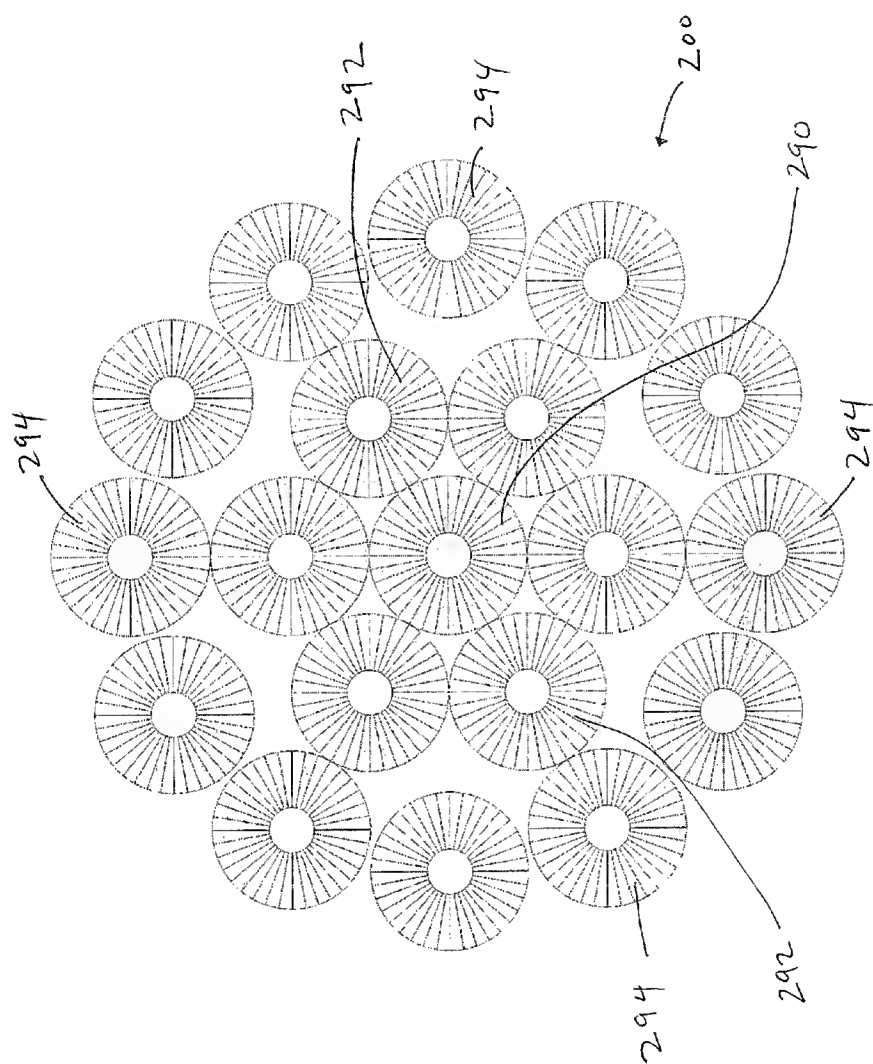


Fig. 9

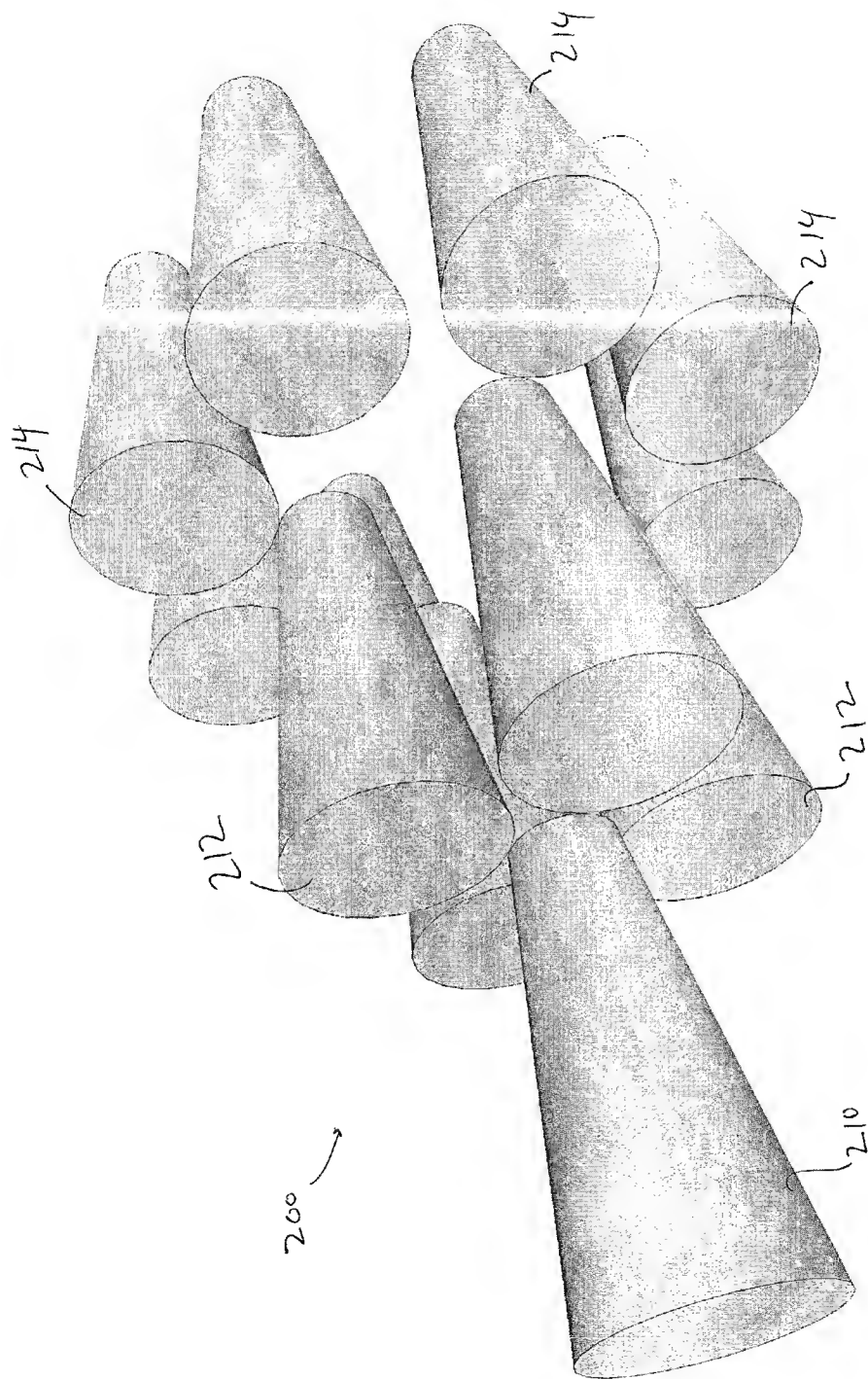


Fig. 10

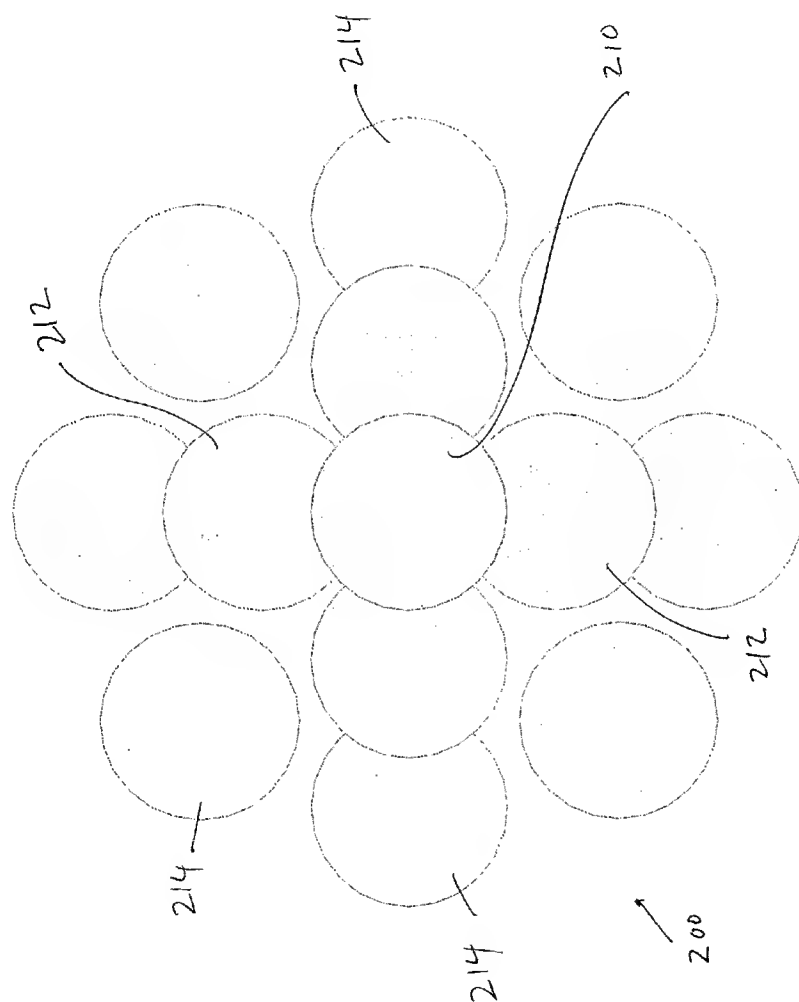


Fig. 11

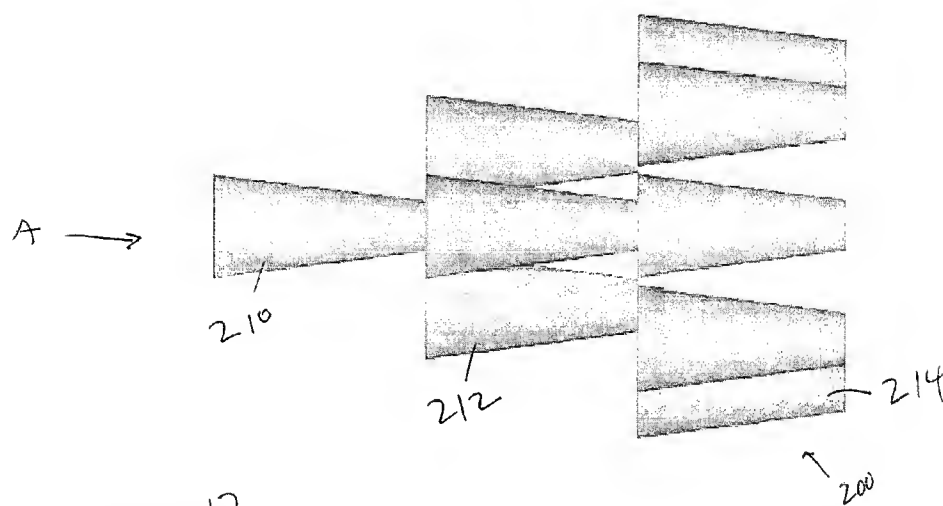


Figure 12

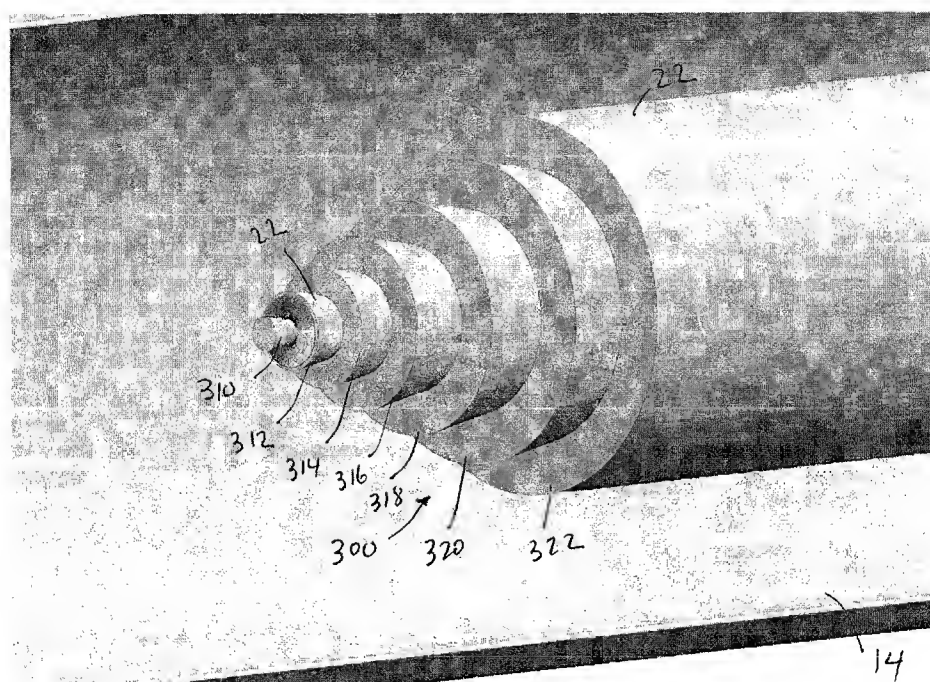


Fig. 13

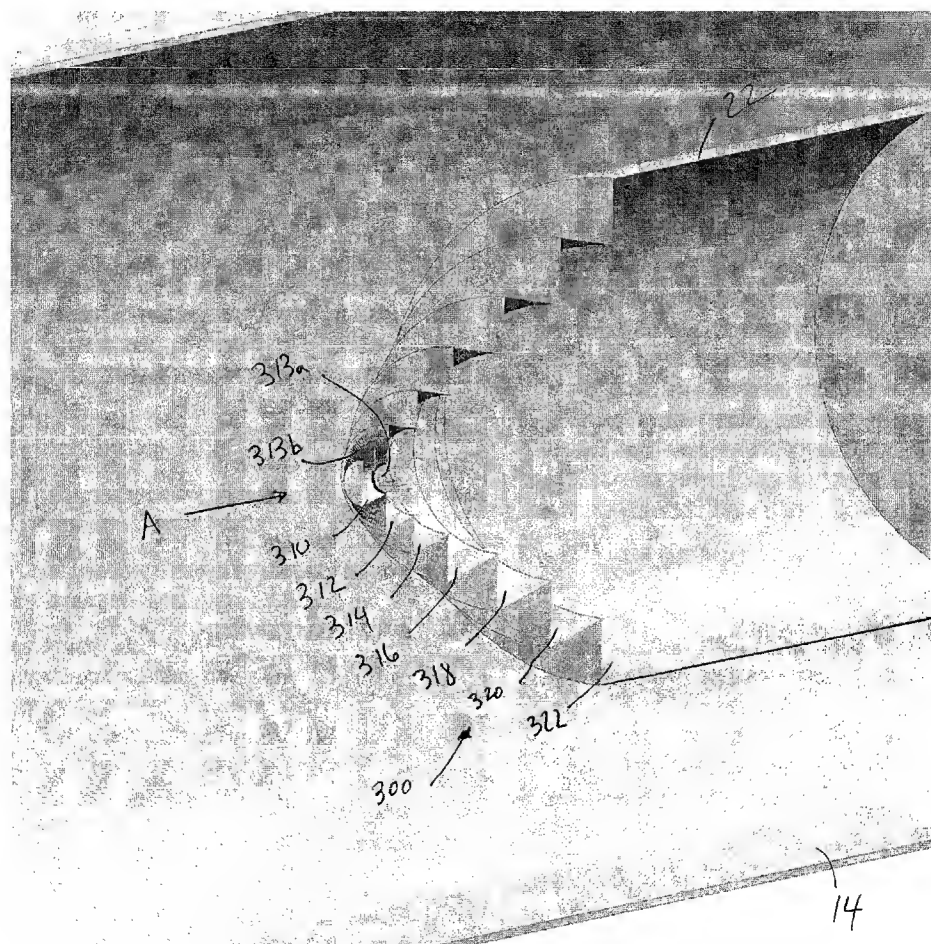


Fig. 14

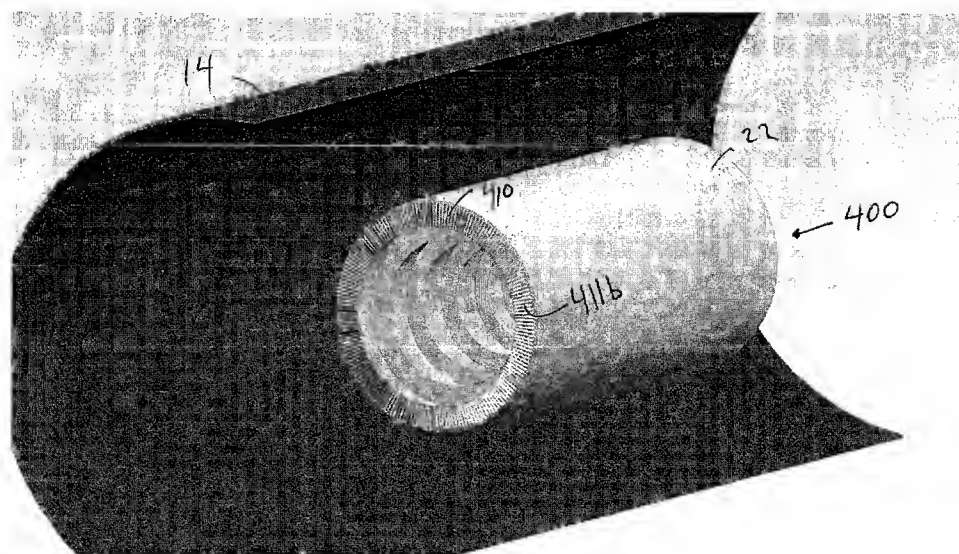


Fig. 15



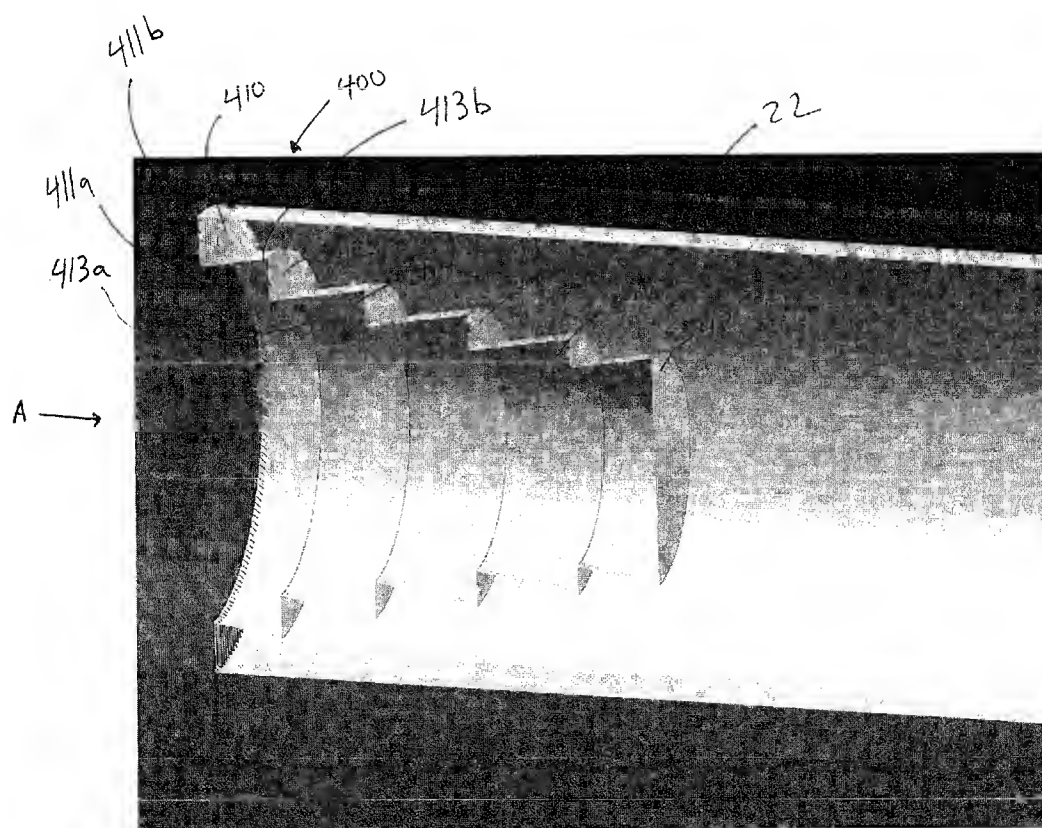


Fig. 16

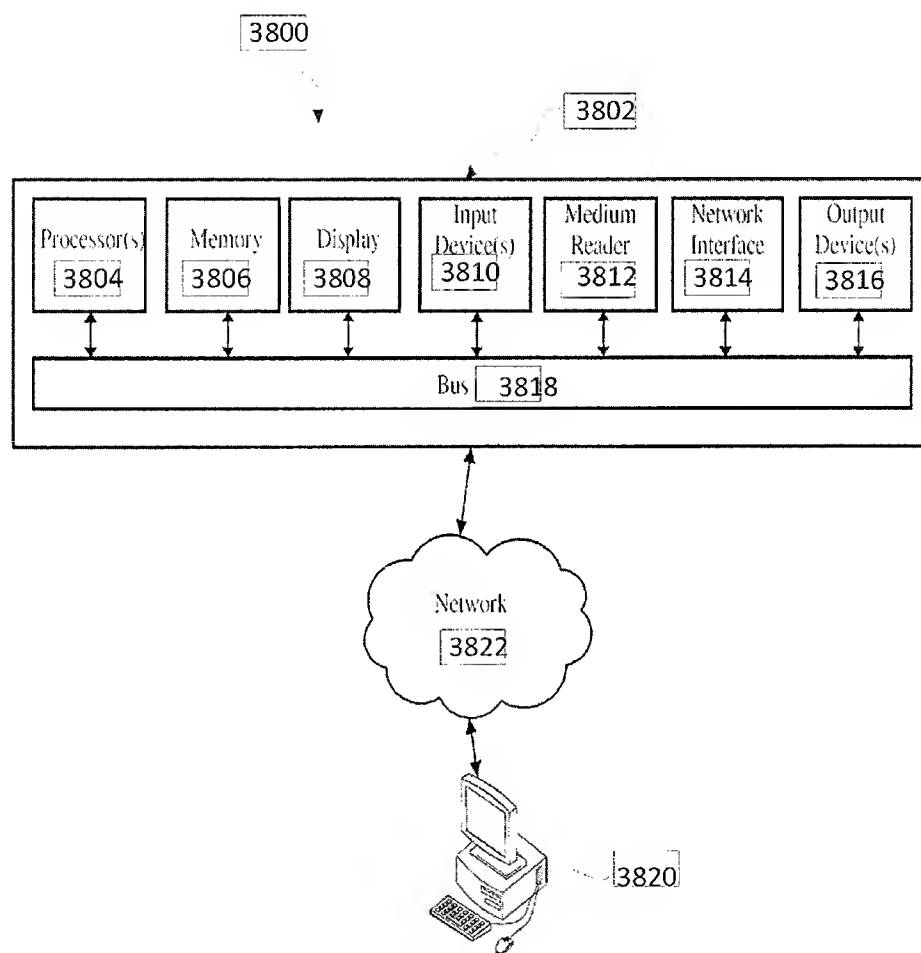


Figure 17

## AXIAL COMPRESSOR CONFIGURATION

### CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefits of U.S. Provisional Application No. 62/113,511 filed on Feb. 8, 2015, and of U.S. Provisional Application No. 62/240,718 filed on Oct. 13, 2015, the disclosures of which are expressly incorporated by reference herein in their entireties.

### FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to an axial compressor and a method for operating an axial compressor.

### BACKGROUND OF THE DISCLOSURE

[0003] Traditional transportation modes via water, land, rail and air revolutionized the movement and growth of our current culture. However, the adverse environmental, societal and economic impacts of these traditional transportation modes initiated a movement to find alternative transportation modes that take advantage of the significant improvements in transportation technology and efficiently move people and materials between locations. High speed transportation systems utilizing rails or other structural guidance components have been contemplated as a solution to existing transportation challenges while improving safety, decreasing the environmental impact of traditional transportation modes and reducing the overall time commuting between major metropolitan communities.

[0004] One transportation system utilizes a low-pressure environment in order to reduce drag on a vehicle at high operating speeds, thus providing the dual benefit of allowing greater speed potential and lowering the energy costs associated with overcoming drag forces. These systems are embodied by a tubular structure in which a near vacuum exists within the tube.

[0005] A range of possibilities exist when optimizing a vehicle's design for travelling inside of a low-pressure tube. At one extreme, the vehicle may have a frontal cross-sectional area that is much smaller than that of the tube, e.g., akin to a needle moving inside of a large tube. The vehicle is relatively small and the tube wall provides very little influence on the vehicle. The working fluid in the tube, such as air, is free to move around the needle with little restriction or pressure build-up in front of the needle.

[0006] At the other extreme, the vehicle's frontal cross-sectional area is approximately the same size as the tube, e.g. a piston moving inside of a large tube with very small wall clearance (known as the "syringe effect"). With such a configuration, it is difficult for the working fluid to move around the vehicle, and pressure will build up in front of the vehicle, which greatly increases the drag force on the vehicle in the tube.

[0007] The tradeoff between these two extremes is either building an enormous, expensive tubular structure to avoid significant flow choking on the vehicle, or using a tight-fitting, material-efficient tubular structure that necessitates a significant drag penalty which must be overcome by the vehicle. It is thus desirable to achieve the best of both worlds, such as a tube that is only slightly larger than the vehicle, but with very low drag.

[0008] Turbofan or turbojet engines utilize a diffuser prior to the air inlet to slow the high speed flow to lead to more

efficient compression; however, this technique works better in a free-stream condition where the flow that is not taken into the engine intake is easily passed around the vehicle nacelle. When a vehicle is travelling at high speed through an enclosed environment, the flow that is passed around the vehicle nacelle can choke in the space between the nacelle cover and the tube wall. Essentially, the flow inside the nacelle decelerates while the flow outside accelerates.

[0009] Axial compressors typically include rotating and stationary components. A shaft drives a central drum, retained by bearings, which has a number of annular airfoil rows attached usually in pairs, one rotating and one stationary attached to a stationary tubular casing. A pair of rotating and stationary airfoils is called a stage. The rotating airfoils, also known as blades or rotors, accelerate the working fluid. The stationary airfoils, also known as stators or vanes, convert the increased rotational kinetic energy into static pressure through diffusion and redirect the flow direction of the fluid, preparing it for the rotor blades of the next stage. The cross-sectional area between rotor drum and casing is reduced in the flow direction in an effort to maintain an optimum Mach number using variable geometry as the fluid is compressed.

[0010] An issue that can face compressors operating in a tubular structure, in particular axial compressors driven by a common driveshaft, is that they can suffer loss of performance and/or catastrophic failure due to stall. Stall is primarily caused by flow separating from compressor blades. Flow separation is in large part caused by flow hitting the blades at a sub-optimal angle of attack or in regions with adverse pressure gradients. Flow separation is exacerbated further by high Mach numbers caused by local flow accelerating to supersonic speeds and causing shock waves on the blades; and low Reynolds numbers caused by laminar flow that is more prone to separation. At high Reynolds numbers, turbulence sometimes helps re-attaching a separated flow back onto the blade.

[0011] Further, axial compressors can suffer performance losses due to shock waves. Shock waves can be the result of high local Mach numbers. The relative velocities and Mach numbers are higher near the tips of blades where the tangential component of the velocity vector is highest due to the larger radiuses/diameters.

### SUMMARY OF THE DISCLOSURE

[0012] An axial compressor includes a housing and a plurality of stages arranged within the housing and along an airflow direction, each stage of the plurality of stages comprising a first blade assembly and a second blade assembly, wherein the first blade assembly is a rotor, each rotor in each first blade assembly being drivable independently from the rotors in the other first blade assemblies.

[0013] Also included may be an electric motor attached to each rotor. A central shaft about which the rotors rotate may be provided, wherein each electric motor is mounted to the central shaft. Each electric motor may be mounted to an inside of the housing.

[0014] A sensor configured to detect an airflow condition may be provided, wherein each rotor is independently drivable in accordance with the detected airflow condition.

[0015] The second blade assembly may be a counter-rotating rotor configured to rotate in an opposite rotational direction of the rotors, each counter-rotating rotor being drivable independently from the other counter-rotating rotor and rotors. Also, an electric motor may be attached to each rotor

and counter-rotating rotor. A central shaft about which the rotors and counter-rotating rotors rotate may be provided, wherein each electric motor is mounted to the central shaft. Each electric motor may be mounted to an inside of the housing.

**[0016]** A sensor configured to detect an airflow condition may be provided, wherein each rotor and counter-rotating rotor is independently drivable in accordance with the detected airflow condition.

**[0017]** A vehicle may be provided, the front end to which the compressor is mounted. Also provided may be a tube through which the vehicle is configured to travel.

**[0018]** An aspect of the disclosure provides an axial compressor includes a housing and a plurality of stages arranged within the housing and along an airflow direction, each stage of the plurality of stages comprising a rotor and a counter-rotating rotor, each counter-rotating rotor being driveable independently from the counter-rotating rotors in the other stages. A vehicle may be provided, the front end to which the compressor is mounted. Also provided may be a tube through which the vehicle is configured to travel.

**[0019]** Another aspect of the disclosure provides method for operating an axial compressor having a plurality of stages arranged within a compressor housing and along an airflow direction, each stage of the plurality of stages having a first blade assembly and a second blade assembly, the method including detecting, via a sensor, an airflow condition of the axial compressor, and driving, via an electric motor, at least one of the first blade assemblies and second blade assemblies independently, in accordance with the detected airflow condition.

**[0020]** The compressor may be mounted to a front end of a vehicle, and the vehicle may be operated to travel within a tube.

**[0021]** A further aspect provides an axial compressor system including a central axial compressor, and a first plurality of axial compressors arranged about a longitudinal axis of the central axial compressor. The first plurality of axial compressors may be arranged downstream of the central axial compressor.

**[0022]** A second plurality of axial compressors arranged about the first plurality of axial compressors may be provided. The second plurality of axial compressors may be arranged downstream of the first plurality of axial compressors. The second plurality of axial compressors may be staggered in the circumferential direction with respect to the first plurality of axial compressors. Each axial compressor of the first plurality of axial compressors and central axial compressor may be drivable independently from the other axial compressors.

**[0023]** A vehicle may be provided, the front end to which the compressor is mounted. Also provided may be a tube through which the vehicle is configured to travel.

**[0024]** Yet another aspect of the disclosure provides a transportation system having a vehicle configured to travel through at least one tube between stations, the vehicle including a first compressor having a first diameter which narrows in a direction of air flow, the first compressor including a first intake configured to ingest gas, and a first exhaust configured to expel compressed gas. Further included is a second compressor coaxial with and positioned downstream from the first compressor and having a second diameter greater than the first diameter, the second compressor having a central aperture in communication with the exhaust of the first compressor, a ring-shaped intake surrounding the central aperture and

configured to ingest gas uncompressed by the first compressor, and an exhaust configured to expel gas compressed by the first and second compressors.

**[0025]** Yet a further aspect of the disclosure provides a transportation system comprising a vehicle configured to travel through at least one tube between stations, the vehicle having a first compressor having a first diameter and including a first intake configured to ingest and compress gas, a central aperture surrounded by the intake, and a first exhaust configured to expel the compressed gas, and a second compressor coaxial with and positioned downstream from the first compressor and having a second diameter that is smaller than the first diameter and that increases in the direction of airflow. The second compressor has a second intake configured to ingest gas passed through the central aperture uncompressed by the first compressor, and a second exhaust configured to expel gas, wherein gas expelled by the first and second exhausts are combined.

**[0026]** Other exemplary embodiments and advantages of the present disclosure may be ascertained by reviewing the present disclosure and the accompanying drawings, and the above description should not be considered to limit the scope of the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0027]** The novel features which are characteristic of the systems, both as to structure and method of operation thereof, together with further objects and advantages thereof, will be understood from the following description, considered in connection with the accompanying drawings, in which a presently preferred embodiment of the system is illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and they are not intended as a definition of the limits of the system. For a more complete understanding of the disclosure, as well as other aims and further features thereof, reference may be had to the following detailed description of the disclosure in conjunction with the following exemplary and non-limiting drawings wherein:

**[0028]** FIG. 1 shows a schematic view of the transportation system according to an aspect of the disclosure;

**[0029]** FIG. 2 shows a view of an exemplary capsule for use in the transportation system in accordance with an aspect of the disclosure;

**[0030]** FIG. 3 shows a sectional perspective schematic view of a compressor according to an aspect of the disclosure;

**[0031]** FIG. 4 shows a sectional perspective schematic view of a compressor according to an aspect of the disclosure;

**[0032]** FIG. 5 shows a side sectional schematic view of a compressor according to an aspect of the disclosure;

**[0033]** FIG. 6 shows a side sectional schematic view of a compressor according to an aspect of the disclosure;

**[0034]** FIG. 7 shows a schematic diagram of influences upon the compressor according to an aspect of the disclosure;

**[0035]** FIG. 8 shows a front plan schematic view of a compressor system according to an aspect of the disclosure;

**[0036]** FIG. 9 shows a front plan schematic view of a compressor system according to an aspect of the disclosure;

**[0037]** FIG. 10 shows a schematic perspective view of a compressor system according to an aspect of the disclosure;

**[0038]** FIG. 11 shows a front plan schematic view of a compressor system according to an aspect of the disclosure;

**[0039]** FIG. 12 shows a side schematic view of a compressor system according to an aspect of the disclosure;

[0040] FIG. 13 shows a perspective view of a serial compressor system according to an aspect of the disclosure;

[0041] FIG. 14 shows a sectional perspective view of the serial compressor system of FIG. 13;

[0042] FIG. 15 shows a sectional perspective view of a serial compressor system according to a further aspect of the disclosure;

[0043] FIG. 16 shows a sectional perspective view of the serial compressor system of FIG. 15; and

[0044] FIG. 17 is an exemplary system for use in accordance with the embodiments described herein.

#### DETAILED DESCRIPTION

[0045] In the following description, the various embodiments of the present disclosure will be described with respect to the enclosed drawings. As required, detailed embodiments of the present disclosure are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present disclosure.

[0046] The particulars shown herein are by way of example and for purposes of illustrative discussion of the embodiments of the present disclosure only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the present disclosure. In this regard, no attempt is made to show structural details of the present disclosure in more detail than is necessary for the fundamental understanding of the present disclosure, the description is taken with the drawings making apparent to those skilled in the art how the forms of the present disclosure may be embodied in practice.

[0047] As used herein, the singular forms “a,” “an,” and “the” include the plural reference unless the context clearly dictates otherwise. For example, reference to “a magnetic material” would also mean that mixtures of one or more magnetic materials can be present unless specifically excluded.

[0048] Except where otherwise indicated, all numbers expressing quantities used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and claims are approximations that may vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not to be considered as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should be construed in light of the number of significant digits and ordinary rounding conventions.

[0049] Additionally, the recitation of numerical ranges within this specification is considered to be a disclosure of all numerical values and ranges within that range. For example, if a range is from about 1 to about 50, it is deemed to include, for example, 1, 7, 34, 46.1, 23.7, or any other value or range within the range.

[0050] The various embodiments disclosed herein can be used separately and in various combinations unless specifically stated to the contrary.

#### Transportation System Overview

[0051] Referring to FIG. 1, a transportation system 10 in accordance with the present disclosure is illustrated. Transportation system 10 includes one or more capsules or transport pods 12 traveling through at least one tube 14 between one or more stations 16. In one exemplary embodiment of the present disclosure, the one or more capsules of the transportation system move through a low pressure environment within the at least one tube 14. In accordance with aspects of the disclosure, a low pressure environment includes any pressure that is below 1 atmosphere (or approximately 1 bar) at sea level.

[0052] Some elements of a high-speed transportation system are discussed in commonly-assigned U.S. application Ser. No. 15/007,783, entitled “Transportation System,” filed on even date herewith, the entire contents of which are expressly incorporated by reference herein.

[0053] In one feature of the present disclosure, a system includes a partially-evacuated cylindrical tube that connects the stations in a closed loop system. Tubes are sized for optimal air flow around the capsule to improve performance and energy consumption efficiency at the travel speed. This low pressure environment minimizes the drag force on the capsule while maintaining the relative ease of pumping out the air from the tube.

[0054] In embodiments, the capsule may be levitated using a pressurized fluid flow (e.g., air) exiting out, e.g., a bottom side of the capsule and interacting with a corresponding track. While embodiments of the present disclosure are directed to using a low pressure environment, in some contemplated embodiments, the environment may be at atmospheric pressure (i.e., not a low pressure environment), which may be easier to maintain as compared to a low pressure environment. For example, with some shorter travel distances (for example, short enough that the capsule may not easily attain a high speed before needing to slow down again), it may be more efficient to run the system in an environment that is at atmospheric pressure to, for example, reduce costs of maintaining a low pressure environment. For example, if a route was only 30 km long, the pod will not be able to achieve its top speed (due to relatively short distance of the route). In such embodiments, the disclosure contemplates that it may be unnecessary to reduce the operating pressure of the environment below atmospheric pressure.

[0055] In accordance with aspects of the disclosure, in embodiments, the pressure of the environment may be, by design, operating at a uniform pressure (e.g., a uniform low pressure). The inventors contemplate, however, that embodiments of the disclosure may include different regions that are operating at different pressures (e.g., two different low pressures).

[0056] In accordance with aspects of the disclosure, the capsules, sections of the tube, and the track are able to communicate with each other so as to, for example, control a capsule traveling within the tube and/or control operating conditions of the tube or track. For example, spacing between capsules within the same tube may be maintained using autonomous vehicles that are aware of the other capsules' relative location. Additional aspects, embodiments and details of a high-speed transportation system are discussed in

commonly-assigned U.S. application Ser. No. 15/007,718, entitled "DEPLOYABLE DECELERATOR," filed on even date herewith, the entire contents of which are expressly incorporated by reference herein. For example, if a vehicle ahead on the tube path has slowed (e.g., due to a malfunction), then the other capsules upstream of the slowed capsule may recognize the situation, and may slow the velocity of the upstream capsules. As a further example of communication between elements of the system in order to control operating conditions, during a seismic event, portions of a tube that detect the seismic activity (e.g., are closer in proximity to the epicenter of the seismic activity), may communicate with portions of the tube further from the epicenter to adjust operating conditions of the tube (e.g., thermal expansion joints, or vibration dampening elements) to account for the seismic activity.

[0057] In embodiments, should there be a loss of communication between capsules themselves, the capsules and the track or tube, the system will shut down the system, and for example, let air pressure into the tube so as to assist in deceleration of the capsules. That is, by removing or reducing the low pressure environment in the tube (e.g., bringing the pressure to atmospheric pressure), the capsules will encounter greater air resistance, which causes the capsules to slow down.

[0058] Referring now to FIG. 2, an exemplary and non-limiting depiction of a capsule or transport pod 12 of the transportation system is illustrated. In embodiments, the capsule 12 may be streamlined to reduce an air drag coefficient as the capsule 12 travels through the low-pressure environment of the at least one tube 14 of the transportation system. In accordance with aspects of the disclosure, in embodiments, a compressor 20 arranged proximate or at the front end of the capsule is operable to ingest at least a portion of the incoming air (instead of displacing the air around the vehicle). For example, as schematically shown in the exemplary embodiment of FIG. 2, in embodiments, the capsule 12 may include the compressor 20 at its leading face. In embodiments, the compressor 20 may include a diffuser, and is operable to ingest oncoming air and utilize the compressed air for the levitation process (when, for example, the capsules are supported via air bearings that operate using a compressed air reservoir and aerodynamic lift). Additionally, as schematically shown in the exemplary embodiment of FIG. 2, in embodiments, the compressed air may be used to spin a turbine, for example, located at the rear end of the capsule, to provide power to the capsule 12.

#### Compressor Configuration

[0059] As shown in FIG. 2, the capsule (also called a "vehicle") 12 includes one or more onboard compressors 20. In accordance with aspects of the disclosure, the compressor 20 allows the capsule to traverse the relatively narrow tube 14 without impeding air flow that travels between the capsule and the walls of the tube. For example, operation of the capsule 12 through the tube 14 may result in a build-up of air mass in front of the capsule 12, which may increase the drag coefficient. The compressor 20 is operable to compress air that is bypassed through the capsule 12. That is, instead of the oncoming air being passed around the capsule 12, in embodiments, the compressor 20 is operable to ingest at least a portion of the oncoming air, so as to reduce drag on the capsule 12. In exemplary and non-limiting embodiments, the compressor ratio of the compressor may be 30/1, may be 4/1,

or may be somewhere within this range, depending on the requirements of a particular application. It is also noted that while the vehicle 12 described herein refers to a pod traveling through a tube, it is contemplated that the compressor 20 and compressor system 200 can be used in other applications, including but not limited to stationary or mobile household, commercial or industrial applications, aircraft, hovercraft, trains and the like.

[0060] In embodiments, the compressor 20 may also supply air to, e.g., a bottom side of the capsule 12 to air bearings, which provide a cushion of air to support the weight of the capsule throughout the journey.

[0061] Referring to FIG. 3, the compressor 20 is housed within a housing 22, and includes a plurality of stages 24 longitudinally arranged in the direction of airflow A. In embodiments, ten to twenty stages 24 are used in the compressor 20; however, those skilled in the art will appreciate that fewer than ten or greater than twenty stages may be employed in alternative embodiments, depending on the requirements of the application. Each stage includes a rotor 26 and a stator 28 which serve to compress and pass a working fluid (e.g., air or other gas) out an exhaust 30. In embodiments, the diameter of the housing 22 is reduced in the direction of airflow A in order to assist in the compression of the working fluid. In such embodiments, each stage 24 (and the rotor 26 and stator 28 therein) also have diameters that are reduced in the direction of airflow A.

[0062] A feature of the disclosure provides independent stage control to create an efficient compression system which dramatically increases the speed of the vehicle with little drag penalty and decreases tube size. The stages 24 do not need to have a shaft, although in some embodiments it can, and each stage can be driven independently. In this regard, each rotor 26 is independently driven by a motor 32a, 32b. In other words each rotor 26 can be operated at a rotational speed independent of the rotational speeds of the other rotors. Each rotor may be driven by its own motor 32a, 32b, or may be driven by a single motor via, e.g., a reduction gear system. Driving the rotors 26 independently allows the compressor 20 to bypass flow around the payload with some thrust generation, which is a significantly different type of engine than what is presently embodied by known turbo-fan or jet engines. Further, it is appreciated by those skilled in the art that the motors 32a, 32b may be electric or may be powered by another power source, depending on the requirements of the particular application.

[0063] As shown in FIG. 5, sensors 3810 and/or feedback control mechanisms (described below) monitor conditions related to the compressor 20 (such as airflow in and around the compressor), and the system 3800 can receive this information and (where necessary) adjust and re-adjust the rotational speed of each rotor 26 when a predetermined threshold or condition is reached, such as the detection of flow separation, stall and/or shocks, by communicating with and instructing each motor 32a, 32b as necessary. It is noted that motors 32a, 32b of each stage and/or of the entire system may be in communication with each other over the system 3800, via computer(s) 3820 (See also FIG. 17). While FIG. 5 shows a single sensor 3810 inside the housing, it is understood by those skilled in the art that multiple sensors may be used inside and/or outside the housing, depending on the application. Further, the sensor(s) 3810 of FIG. 5 and described herein can be used in connection with any embodiments of the invention disclosed herein. It is further noted that the sensor

(s) **3810** may include an optical sensor, Hall effect sensor, a combination of these two sensors, or any other type of suitable sensor.

**[0064]** The disclosure also provides for fine control of the angle of attack and relative velocity of the flow hitting the blades to eliminate or mitigate flow separation and subsequent stall. In another feature of the disclosure, as shown in FIG. 4, each stage **24** includes a rotor **26** and a counter-rotating rotor **28'** (rather than a stator), which rotates in a rotational direction opposite that of the rotational direction of the rotor. Similar to the rotors **26**, each counter-rotating rotor **28'** may be driven by an electric motor, which can be its own motor **32a**, **32b** (independent of the motor used to drive the rotor), or may be driven by a single motor via, e.g., a reduction gear system, or may be driven by a motor common to each stage (such that the common stage motor drives the rotor **26** and counter-rotating rotor **28'**).

**[0065]** Utilizing counter-rotating rotors allows the system **3800** to control the angle of attack of the flow hitting the blades of the counter-rotating rotor by varying the RPM (revolutions per minute) of the counter-rotation, instead of relying on a complicated system of actuators changing the mounting angle of stator blades. It is noted that in accordance with a feature of the disclosure, the counter-rotating rotors **28'** may be driven independently of each other, while the rotors **26** are driven together, and that the rotors **26** may be driven independently of each other, while the counter-rotating rotors **28'** are driven together. Still further, the rotors **26** may be driven together in a rotational direction, while the counter-rotating rotors **28'** are driven together in a rotational direction opposite the rotational direction of the rotors.

**[0066]** FIG. 7 shows a schematic diagram of the various influences upon the compressor. More specifically, reference **2601** shows a rotor blade of a first stage rotor **26**, reference **2602** shows a rotor blade of a second stage rotor, reference **2603** shows a rotor blade of a third stage rotor. Similarly, reference **2801** shows a rotor blade of a first stage counter-rotating rotor **28'**, and reference **2802** shows a rotor blade of a second stage counter-rotating rotor **28'**. Directional arrow **Av** represents the absolute velocity of the blade immediately behind it, directional arrow **Tv** represents the tangential velocity of the blade immediately behind it, and directional arrow **Rv** represents the relative velocity of the blade immediately behind it. **AL** represents the aerodynamic limit of the blade immediately behind it.

**[0067]** It is further noted that the system **3800** can utilize the above-described sensors **3810** and feedback control mechanisms to adjust and re-adjust the rotational speed of each rotor **26** and counter-rotating rotor **28'** when the predetermined threshold or condition is reached.

**[0068]** It is additionally noted that the motor **32a** for each rotor **26** and/or counter-rotating rotor **28'** may be mounted inside the hub of each rotor, as shown in FIG. 5. The motors **32b** may alternatively or additionally be mounted to the inside of the housing **22**, as shown in FIG. 6, or the motors **32a**, **32b** may be mounted to the outside of the housing **22**, mounted to a shaft about which the rotors **26**, **28'** rotate, or elsewhere by using e.g., shafts, gears, belts, or other modes of transmitting power to the rotors **26** and/or counter-rotating rotors **28'**. The mounting of the motors **32a**, **32b** may also include a magnetic bearing mechanism simultaneously, and/or air bearings (wherein air is supplied by, e.g. the compressor **20**) in order to bypass the need for conventional mechanical bearings.

**[0069]** It is also noted that the compressor may provide torque to a shaft, including but not limited to reciprocating engines, rotary engines, generators, internal combustion engines, turbines **13** including gas turbines, flywheels, compressed gas engines, and hydraulic motors.

**[0070]** FIGS. 8-14 show varying aspects of a compressor system **200** made of a plurality of smaller diameter compressors which fit within the vehicle **12**, rather than a single, larger-diameter compressor **20**. Use of using a plurality of smaller compressors allows the compressors to spin at higher RPM without the risk of producing supersonic speeds near their tips. Further, in the event of failure of one or more compressors in the system, the remaining operational compressors can still carry out their intended function (e.g., propelling the vehicle **12**) and may even compensate for the loss of a compressor.

**[0071]** FIG. 8 shows a compressor system **200** having a central compressor **280**, surrounded by a ring of six surrounding compressors **282**, although it is understood by those skilled in the art that more or fewer surrounding compressors **282** may be used, depending on the application. FIG. 9 shows a compressor system **200** having a central compressor **290**, surrounded by a first ring of surrounding compressors **292**, which are in turn surrounded by a second ring of surrounding compressors **294**, although it is understood by those skilled in the art that more or fewer surrounding compressors **292**, **294** than shown in FIG. 9 may be used. Further, it is noted that while each compressor **280**, **282**, **290**, **292**, **294** is arranged along a plane orthogonal to the airflow direction **A**, it is understood by those skilled in the art that the compressors **280**, **282** may be arranged along different planes.

**[0072]** In this regard, FIGS. 10-12 show a compressor system with staggered compressors **210**, **212**, **214** arranged along different planes. The first central compressor **210** is surrounded by a first ring of surrounding compressors **212** which are downstream in the airflow direction **A** from the first central compressor. A second ring of surrounding compressors **214** surrounds and is downstream from the first ring of surrounding compressors **212**. It is also understood by those skilled in the art that more or fewer surrounding compressors **212**, **214** than shown may be used. When using compressors **210**, **212**, **214** which have a housing tapered downstream of the airflow direction **A** (as shown in FIGS. 10-12), the compressors may be arranged more tightly together (best seen in FIG. 11), thereby minimizing "dead" surface area, or compressor gaps, along the face of the vehicle **12**. It is further also understood by those skilled in the art that each compressor of the compressor system **200** is independently controllable.

**[0073]** FIGS. 13-14 shows a serial compressor system **300** in a further feature of the disclosure. A first central compressor **310** has a housing **22** having diameter which narrows, or tapers, in a direction of air flow **A**. The first central compressor **310** is configured to compress high speed flow at a reduced size and mass than that of the full diameter of the tube **14**. The first central compressor **310** compresses the working fluid (e.g. air), enough to decrease the diameter of the flow, which allows the airflow about the exterior of the housing to decelerate. A second compressor **312** is coaxial with and positioned downstream from the first compressor, has a housing **22** diameter greater than that of the first central compressor, and narrows in the direction of air flow. The second compressor **312** has a central aperture **313a** in communication with the exhaust of the first central compressor **310** such



that the exhaust from the first central compressor **310** is fed into this central aperture, but is not compressed by the second compressor. The second compressor **312** includes a ring-shaped intake **313b** surrounding the central aperture **313a** and configured to ingest air uncompressed by the first central compressor **310**. The exhaust from the second compressor **312** may combine with the exhaust from the first central compressor **310** and is further passed downstream to a third compressor **314** which is similarly configured to the second compressor **312**, but has a larger housing diameter.

[0074] The remaining downstream serial compressors **316**, **318**, **320** and **322** are similarly configured as the upstream compressors **310**, **312**, **314** each successively having a larger housing diameter. The final compressor **322** is similarly configured to the upstream compressors **310**, **312**, **314**, **316**, **318**, **320**, but may have a housing that is generally parallel to the tube **14**. While FIGS. **13-14** show seven compressors, it is appreciated by those skilled in the art that more or fewer compressors may be used, depending on the requirements of the particular application. For example, serial compressors may be repeatedly provided until the desired pressure ratio is achieved. Each subsequent serial compressor has a substantially decreasing inlet Mach number. The internal flow passages of each compressor are initially substantially separate, but may be combined downstream and flow out in a single passage.

[0075] FIGS. **15-16** shows a serial compressor system **400** in a further feature of the disclosure, which differs from the system of FIGS. **13-14** primarily in that the different stages of the compressor are serially stacked from the outside inwardly. A first ring-like compressor **410** has a central aperture **411a** through which incoming air to subsequent compressors **412**, **414**, **416**, **418**, **420** is passed, and has an inlet **411b** configured to receive and compress as exhaust a working fluid (e.g., air). The first compressor **410** also has a housing **22** that is generally parallel to the tube **14** and contiguous with the exterior of the vehicle **12**. A second ring-like compressor **412** is coaxial with and positioned downstream from the first compressor, has a housing **22** diameter that is smaller than that of the first compressor **410**, and is flared in the direction of air flow **A**. The second compressor **412** has a central aperture **413a** through which incoming air to subsequent compressors **414**, **416**, **418**, **420** is passed. The exhaust air compressed by inlet **413b** of the second compressor is combined with the exhaust air compressed by the first compressor **410**.

[0076] Remaining downstream serial compressors **414**, **416**, **418** are similarly configured as the compressors **410**, **412** upstream from them, each successively having a flared, smaller housing diameter. The final compressor **420** is not a ring-like compressor but rather is similar to the compressors **20** described with reference to FIGS. **3-6**, and has a flared housing that is the smallest of the upstream compressors in diameter. While FIGS. **15-16** show six compressors, it is appreciated by those skilled in the art that more or fewer compressors may be used, depending on the requirements of the particular application. For example, serial compressors may be repeatedly provided until the desired pressure ratio is achieved. The diffusing action after each serial compressor slows the flow and increases the static pressure prior to entering each new stage. Each compressor may be independent and driven from motors on the outer wall. The flow after each stage recombines and moves down stream. The final compressor **420** is provided at a reduced Mach number inlet.

[0077] It is also understood by those skilled in the art that the compressor systems **200**, **300**, **400** can be used with any of the aforementioned features and embodiments described in relation to, e.g., FIGS. **1-7** and **17**.

#### System Environment

[0078] As will be appreciated by one skilled in the art, aspects of the present disclosure may be embodied as a system, a method or a computer program product. Accordingly, embodiments of the present disclosure may take the form of an entirely hardware embodiment, an entirely software (excluding the transducers and A/D converters) embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in any tangible medium of expression having computer-usable program code embodied in the medium.

[0079] Any combination of one or more computer usable or computer readable medium(s) may be utilized. The computer-usable or computer-readable medium may be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a non-exhaustive list) of the computer-readable medium would include the following:

- [0080] an electrical connection having one or more wires,
- [0081] a portable computer diskette,
- [0082] a hard disk,
- [0083] a random access memory (RAM),
- [0084] a read-only memory (ROM),
- [0085] an erasable programmable read-only memory (EPROM or Flash memory),
- [0086] an optical fiber,
- [0087] a portable compact disc read-only memory (CDROM),
- [0088] an optical storage device,
- [0089] a transmission media such as those supporting the Internet or an intranet,
- [0090] a magnetic storage device
- [0091] a USB key,
- [0092] a certificate,
- [0093] a perforated card, and/or
- [0094] a mobile phone.

[0095] In the context of this document, a computer-usable or computer-readable medium may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The computer-usable medium may include a propagated data signal with the computer-usable program code embodied therewith, either in baseband or as part of a carrier wave. The computer usable program code may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc.

[0096] Computer program code for carrying out operations of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute



entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network. This may include, for example, a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). Additionally, in embodiments, the present disclosure may be embodied in a field programmable gate array (FPGA).

[0097] FIG. 17 is an exemplary system for use in accordance with the embodiments described herein. The system 3800 is generally shown and may include a computer system 3802, which is generally indicated. The computer system 3802 may operate as a standalone device or may be connected to other systems or peripheral devices. For example, the computer system 3802 may include, or be included within, any one or more computers, servers, systems, communication networks or cloud environment.

[0098] The computer system 3802 may operate in the capacity of a server in a network environment, or in the capacity of a client user computer in the network environment. The computer system 3802, or portions thereof, may be implemented as, or incorporated into, various devices, such as a personal computer, a tablet computer, a set-top box, a personal digital assistant, a mobile device, a palmtop computer, a laptop computer, a desktop computer, a communications device, a wireless telephone, a personal trusted device, a web appliance, or any other machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that device. Further, while a single computer system 3802 is illustrated, additional embodiments may include any collection of systems or sub-systems that individually or jointly execute instructions or perform functions.

[0099] As illustrated in FIG. 38, the computer system 3802 may include at least one processor 3804, such as, for example, a central processing unit, a graphics processing unit, or both. The computer system 3802 may also include a computer memory 3806. The computer memory 3806 may include a static memory, a dynamic memory, or both. The computer memory 3806 may additionally or alternatively include a hard disk, random access memory, a cache, or any combination thereof. Of course, those skilled in the art appreciate that the computer memory 3806 may comprise any combination of known memories or a single storage.

[0100] As shown in FIG. 38, the computer system 3802 may include a computer display 3808, such as a liquid crystal display, an organic light emitting diode, a flat panel display, a solid state display, a cathode ray tube, a plasma display, or any other known display. The computer system 102 may include at least one computer input device 3810, such as a keyboard, a remote control device having a wireless keypad, a sensor, a microphone coupled to a speech recognition engine, a camera such as a video camera or still camera, a cursor control device, or any combination thereof. Those skilled in the art appreciate that various embodiments of the computer system 3802 may include multiple input devices 3810. Moreover, those skilled in the art further appreciate that the above-listed, exemplary input devices 3810 are not meant to be exhaustive and that the computer system 3802 may include any additional, or alternative, input devices 3810.

[0101] The computer system 3802 may also include a medium reader 112 and a network interface 114. Further-

more, the computer system 102 may include any additional devices, components, parts, peripherals, hardware, software or any combination thereof which are commonly known and understood as being included with or within a computer system, such as, but not limited to, an output device 116. The output device 116 may be, but is not limited to, a speaker, an audio out, a video out, a remote control output, or any combination thereof.

[0102] Aspects of embodiments of the present disclosure (e.g., control systems for the tube environment, capsule control systems, tube orientation, tube switching systems) can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions and/or software, as described above. The control systems may be implemented and executed from either a server, in a client server relationship, or they may run on a user workstation with operative information conveyed to the user workstation. In an embodiment, the software elements include firmware, resident software, microcode, etc.

[0103] Furthermore, the aspects of the disclosure may take the form of a computer program product accessible from a computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. The software and/or computer program product can be implemented in the environment of FIG. 38. For the purposes of this description, a computer-usable or computer readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable storage medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk—read only memory (CD-ROM), compact disc—read/write (CD-R/W) and DVD.

[0104] Although the present specification describes components and functions that may be implemented in particular embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Such standards are periodically superseded by faster or more efficient equivalents having essentially the same functions. Accordingly, replacement standards and protocols having the same or similar functions are considered equivalents thereof.

[0105] The illustrations of the embodiments described herein are intended to provide a general understanding of the various embodiments. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. Additionally, the illustrations are merely representational and may not be drawn to scale. Certain proportions within the illustrations may be exaggerated, while

other proportions may be minimized. Accordingly, the disclosure and the figures are to be regarded as illustrative rather than restrictive.

**[0106]** Accordingly, the present disclosure provides various systems, servers, methods, media, and programs. Although the disclosure has been described with reference to several exemplary embodiments, it is understood that the words that have been used are words of description and illustration, rather than words of limitation. Changes may be made within the purview of the appended claims, as presently stated and as amended, without departing from the scope and spirit of the disclosure in its aspects. Although the disclosure has been described with reference to particular materials and embodiments, embodiments of the invention are not intended to be limited to the particulars disclosed; rather the invention extends to all functionally equivalent structures, methods, and uses such as are within the scope of the appended claims.

**[0107]** While the computer-readable medium may be described as a single medium, the term “computer-readable medium” includes a single medium or multiple media, such as a centralized or distributed database, and/or associated caches and servers that store one or more sets of instructions. The term “computer-readable medium” shall also include any medium that is capable of storing, encoding or carrying a set of instructions for execution by a processor or that cause a computer system to perform any one or more of the embodiments disclosed herein.

**[0108]** The computer-readable medium may comprise a non-transitory computer-readable medium or media and/or comprise a transitory computer-readable medium or media. In a particular non-limiting, exemplary embodiment, the computer-readable medium can include a solid-state memory such as a memory card or other package that houses one or more non-volatile read-only memories. Further, the computer-readable medium can be a random access memory or other volatile re-writable memory. Additionally, the computer-readable medium can include a magneto-optical or optical medium, such as a disk or tapes or other storage device to capture carrier wave signals such as a signal communicated over a transmission medium. Accordingly, the disclosure is considered to include any computer-readable medium or other equivalents and successor media, in which data or instructions may be stored.

**[0109]** Although the present application describes specific embodiments which may be implemented as code segments in computer-readable media, it is to be understood that dedicated hardware implementations, such as application specific integrated circuits, programmable logic arrays and other hardware devices, can be constructed to implement one or more of the embodiments described herein. Applications that may include the various embodiments set forth herein may broadly include a variety of electronic and computer systems. Accordingly, the present application may encompass software, firmware, and hardware implementations, or combinations thereof.

**[0110]** Although the present specification describes components and functions that may be implemented in particular embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Such standards are periodically superseded by faster or more efficient equivalents having essentially the same functions. Accordingly, replacement standards and protocols having the same or similar functions are considered equivalents thereof.

**[0111]** The illustrations of the embodiments described herein are intended to provide a general understanding of the various embodiments. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. Additionally, the illustrations are merely representational and may not be drawn to scale. Certain proportions within the illustrations may be exaggerated, while other proportions may be minimized. Accordingly, the disclosure and the figures are to be regarded as illustrative rather than restrictive.

**[0112]** One or more embodiments of the disclosure may be referred to herein, individually and/or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any particular invention or inventive concept. Moreover, although specific embodiments have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all subsequent adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the description.

**[0113]** The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b) and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all of the features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description, with each claim standing on its own as defining separately claimed subject matter.

**[0114]** The above disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments which fall within the true spirit and scope of the present disclosure. Thus, to the maximum extent allowed by law, the scope of the present disclosure is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

**[0115]** Accordingly, the novel architecture is intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term “includes” is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term “comprising” as “comprising” is interpreted when employed as a transitional word in a claim.

**[0116]** While the invention has been described with reference to specific embodiments, those skilled in the art will

understand that various changes may be made and equivalents may be substituted for elements thereof without departing from the true spirit and scope of the invention. While exemplary embodiments are described above, it is not intended that these embodiments describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the disclosure. In addition, modifications may be made without departing from the essential teachings of the invention. Furthermore, the features of various implementing embodiments may be combined to form further embodiments of the invention.

1. An axial compressor comprising:  
a housing;  
a plurality of stages arranged within the housing and along an airflow direction, each stage of the plurality of stages comprising a first blade assembly and a second blade assembly, wherein the first blade assembly is a rotor, each rotor in each first blade assembly being drivable independently from the rotors in the other first blade assemblies.
2. The axial compressor according to claim 1, further comprising an electric motor attached to each rotor.
3. The axial compressor according to claim 2, further comprising a central shaft about which the rotors rotate, wherein each electric motor is mounted to the central shaft.
4. The axial compressor according to claim 2, wherein each electric motor is mounted to an inside of the housing.
5. The axial compressor according to claim 1, further comprising a sensor configured to detect an airflow condition, wherein each rotor is independently drivable in accordance with the detected airflow condition.
6. The axial compressor according to claim 1, wherein the second blade assembly is a counter-rotating rotor configured to rotate in an opposite rotational direction of the rotors, each counter-rotating rotor being drivable independently from the other counter-rotating rotor and rotors.
7. The axial compressor according to claim 6, further comprising an electric motor attached to each rotor and counter-rotating rotor.
8. The axial compressor according to claim 7, further comprising a central shaft about which the rotors and counter-rotating rotors rotate, wherein each electric motor is mounted to the central shaft.
9. The axial compressor according to claim 7, wherein each electric motor is mounted to an inside of the housing.
10. The axial compressor according to claim 7, further comprising a sensor configured to detect an airflow condition, wherein each rotor and counter-rotating rotor is independently drivable in accordance with the detected airflow condition.
11. The axial compressor according to claim 1, further comprising a vehicle, the front end to which the compressor is mounted.
12. The axial compressor according to claim 11, further comprising a tube through which the vehicle is configured to travel.

13. An axial compressor comprising:  
a housing;  
a plurality of stages arranged within the housing and along an airflow direction, each stage of the plurality of stages comprising a rotor and a counter-rotating rotor, each counter-rotating rotor being driveable independently from the counter-rotating rotors in the other stages.
14. The axial compressor according to claim 13, further comprising a vehicle, the front end to which the compressor is mounted.
15. The axial compressor according to claim 14, further comprising a tube through which the vehicle is configured to travel.
16. A method for operating an axial compressor having a plurality of stages arranged within a compressor housing and along an airflow direction, each stage of the plurality of stages having a first blade assembly and a second blade assembly, the method comprising:  
detecting, via a sensor, an airflow condition of the axial compressor; and  
driving, via an electric motor, at least one of the first blade assemblies and second blade assemblies independently, in accordance with the detected airflow condition.
17. The method according to claim 16, wherein the compressor is mounted to a front end of a vehicle.
18. The method according to claim 17, further comprising operating the vehicle to travel within a tube.
19. An axial compressor system comprising:  
a central axial compressor; and  
a first plurality of axial compressors arranged about a longitudinal axis of the central axial compressor.
20. The axial compressor according to claim 19, wherein the first plurality of axial compressors are arranged downstream of the central axial compressor.
21. The axial compressor according to claim 19, further comprising a second plurality of axial compressors arranged about the first plurality of axial compressors.
22. The axial compressor according to claim 19, wherein the second plurality of axial compressors are arranged downstream of the first plurality of axial compressors.
23. The axial compressor according to claim 19, wherein the second plurality of axial compressors are staggered in the circumferential direction with respect to the first plurality of axial compressors.
24. The axial compressor according to claim 17, wherein each axial compressor of the first plurality of axial compressors and central axial compressor are drivable independently from the other axial compressors.
25. The axial compressor according to claim 19, further comprising a vehicle, the front end to which the compressor is mounted.
26. The axial compressor according to claim 25, further comprising a tube through which the vehicle is configured to travel.
- 27-28. (canceled)

\* \* \* \* \*